Int. J. on Recent Trends in Engineering and Technology, Vol. 8, No. 2, Jan 2013

# Add-on or Integration? The future of CR Deployment in Real World - An Industrial and Marketing Viewpoint

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*Abstract*—**Cognitive radio (CR) was once considered as a breakthrough technique to reform the field of wireless communication characterized by great spectrum efficiency enhancement. However, for more than a decade years, this technology has been dwelling in the academia without being able to put expertise to good use in industry. The ultimate reason for this phenomenon is the pervasive idea to consider the cognitive radio network (CRN) as an add-on for existing wireless communication systems, an inevitable result caused by CRN related prescriptions made by FCC. This paper analyzes why such an add-on mode for CRN is hard to be accepted by incumbent wireless communication systems from various perspectives. Meanwhile, we analyze feasibility to operate CRNs integrating with incumbent wireless communication systems from both technical and economic perspectives.**

*Index Terms*—**Cognitive Radio, Deployment Mode, Add-on Mode, Integration Mode.**

## I. Introduction

The 21st century witnesses an explosive use of wireless communications. People always want to be interconnected: people may check email, watch videos, play online games and so forth wherever and whenever. All these applications consume both power and radio bandwidth-lots of it. Advanced technology now can put high power volume in devices fitting in our pockets. However spectrum is always a limited resource and technology cannot "create" new spectrum. For most spectrum bands, the service providers should buy the corresponding license from Federal Communications Commission (FCC) before using them. Such spectrum is thus named as "licensed spectrum" and users who use the spectrum are "licensed user". As wireless communication prevails, spectrum licenses become precious commodities and people are already feeling the pinch.With the reality that the spectrum cannot be created at will, the effort should be placed on "fully" utilizing available spectrum. One straightforward phenomenon of "inefficient" spectrum utilization is that the licensed users usually do not use their purchased spectrum all the time at all places. For instance, for the TV system, a TV is usually not receiving program on one channel for 24 hours a day; also, there cannot be a TV set on every square inch in the coverage area of a TV station. An immediate idea is to allow others utilize the spectrum when the licensed users are not using them. This idea breeds the technology of cognitive radio (CR), the notion of which was coined in 1999 by J. Mitola [1].Cognitive radio is the radio that can quickly senses the signal in large scale spectrum and dynamically accesses desired spectrum band, as facilitated by the techniques including compressed sensing [2] and software defined radio [3].After CR notion was formally proposed, myriad research has been conducted from different perspective to try using the technique to help real world. FCC also voted to proceed with opening up vacant broadband spectrum channels to new and innovative wireless devices [4]. However, more than a decade years passed after Mitola's first paper on CR, even the first standard for cognitive radio- IEEE802.22 is still not perfectly finished, let alone large-scale applications of the CR technique.

What is wrong? One culprit might be one constraint prescribed by FCC. Obscured by the amazing sensibility of cognitive radio and appealing merit that cognitive radio can re-use those spectrum already allocated, most people optimistically believe that cognitive radio can be successfully implemented without changing the existing telecommunication systems at all. Under this pervasive optimistic environment, FCC prescribed "no modification to the incumbent system should be required to accommodate opportunistic use of the spectrum by secondary users"[5] as the fundamental requirement for deploying CRNs. (Here secondary user is another name for cognitive radio users who have no spectrum license, and correspondingly primary users refer to those incumbent radios who purchased the license of the spectrum). Since then, many researches are tightly constrained by this prescription to probe for the solutions for constructing the cognitive radio network (CRN) without any change on existing communication systems. We refer to such CRN deployment mode as add-on mode for CRN implementation. Next, we will analyze what difficulties such add-on mode will encounter in reality.

## II. Problem of Add-on Deployment Mode

When the CRN is deployed in the licensed band, the incumbent communication system that paid for the license is usually called as "Primary Network" or "Primary Users", and the CRN is called as "Secondary Network" or "Secondary Users". The key concern for CRN deployment is the feasibility of primary and secondary network coexistence (named as P-S coexistence). In this section, we will analyze the potential issues on the P-S coexistence under the add-on mode.


DOI: 01.IJRTET.8.2.47

Int. J. on Recent Trends in Engineering and Technology, Vol. 8, No. 2, Jan 2013

### *A. Issue of Primary Receiver Detection*

For incumbent communication systems, the spectrum most extensively used is between 300MHz-3GHz. The reason being, the radio waves with frequency more than 3GHz cannot well pass obstacles while radio waves lower than 300MHz require awkwardly large antennas for efficient transmission. When we check the residents living in the swath of spectrum from 300MHz to 3GHz, except cellular systems and unlicensed band (which is always free to use for any device), most communications systems such as TV network, GPS Systems, Navigation Systems and so forth are simplex communication systems, i.e. communication devices can only transmit or only receive. Therefore such a primary network is composed of two types of communication devices, primary transmitter (PT) and primary receiver (PR). The most fundamental requirement for the cognitive radios is that they should not interfere with the reception of active incumbent device, i.e. the CR can only transmit over a channel under the condition that all the primary receivers within the CR's interference range are not active on that channel. When the CRN coexists with a simplex primary network, the premier concern is, the CR can only sense the signal from the primary transmitter but cannot detect the activity of the primary receiver. Therefore it may happen that, as shown in figure 1, when CR senses the PT's signal, but PR is out of the interference range of CR. Therefore such signal sensing may become ineffective.

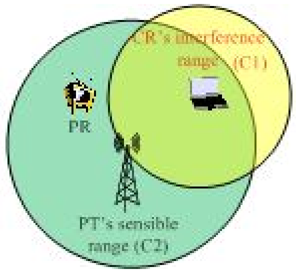


Fig. 1. Ineffectiveness of signal sensing based PR detection

Such issue is aggravated by the following fact: when the signal from the primary transmitter (PT) is sensed by one CR, the probability that the primary receiver (PR) is in the interference range of the CR (named as PR-nearby probability) decreases with sensible range of the primary transmitter's signal. The smaller PR nearby probability $P_{PR}$ denotes less effectiveness of the signal sensing. The reason being, when the primary transmitter's signal covering range increases, it is more possible that two devices that can sense the signal are far away from each other. Therefore PR is less possible nearby and hence the signal sensing becomes more meaningless. Figure 2 gives the result of simulation on the PR-nearby probability $P_{PR}$. The simulation setting is: the transmission range of a PT is $r_c$, (the X-axis in figure 2); the distance between PT and PR is a random variable $r_{TR}$~$U(0, r_c)$; the range within which PT's signal can be sensed (i.e. PT's interference range) is $2r_c$; the CR randomly appeared in any point within the PR's interference range; the interference distance of a CR is also twice of the CR's transmission range.Each simulation data is an average result of 10000 runs. From the simulation result, we can find that when the sensible

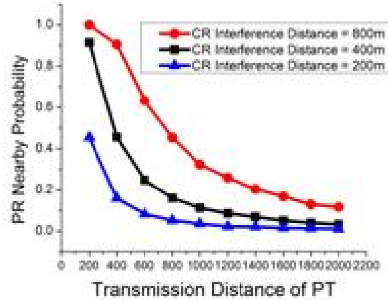


Fig. 2. Simulation on PR detection Effectiveness

range of PT's signal is much larger than the CR's interference range, the PR nearby probability is almost 0, which accords with our analysis. In reality, for civilian use, the CR's transmission range is usually within 0.1 mile; however, in most of existing simplex networks, the PT's transmission distance is much larger (e.g. tens of miles for TV signal) than CR's transmission range. According to the above analysis, the ineffectiveness of signal sensing would be very severe in real simplex primary networks.Another more serious issue is the asynchrony between PT and PR, that is, when the PT is transmitting, the PR may not be receiving. This is very common in reality, for instance, one TV tower may transmit 24 hours a day; however, a person cannot watch TV for 24 hours a day! So in essence, the difficulty of PR activity detection is: when a CR senses a PT's signal, it can hardly assert there is a PR nearby; even a PR does exist, the CR cannot make sure that the PR is receiving the PT's signal. In this case, how about letting the CR only work in the area where the PT's signal can never be sensible? This may work; however, it is no longer P-S coexistence. A more ironical thing is this usually does not need the CR technique at all in reality! For instance in TV network, since the TV towers have fixed locations, we can always know in which area the TV signals are sensible by pre-calculation or on-site detection. Consequently, we can draw a map to mark out the TV-signal free area. Then any communication device can use the corresponding TV spectrum in those TV-signal free areas without relying on CR technique to periodically sensing the TV spectrum. In fact in 2010, FCC Commissioners already ditched the "spectrum sensing" technique but required the secondary user to query a special geolocation database to determine TV-signal free area. This is more like a purely "white-space" technology but not "CR" technology. But this does not eliminate the importance of CR technology. The reason being, the FCC's new rule of giving up spectrum sensing faces the marketing concerns, i.e. the area having no incumbent signals also denotes the depression of the spectrum market in that area. For instance, who is going to For instance, who is going to invest money to build a set of communication system in a desolated area where there is even no TV signal?

### *B. Issue of Sensing Correctness*

In duplex primary network, since a communication device can both transmit and receive, the PR can be indirectly detectedthrough signal sensing. For instance, in a cellular network environment, the CRs can detect a mobile unit's




DOI: 01.IJRTET.8.2.47

Int. J. on Recent Trends in Engineering and Technology, Vol. 8, No. 2, Jan 2013

activity in the channel (if frequency division duplex (FDD) is adopted) or timeslot (if time division duplex (TDD) is adopted) where the mobile unit transmits; then CRs should avoid interfering with active mobile unit on the channel or timeslot where the mobile unit receives. However, when CRNs working in duplex primary network, an immediate question the primary network operators would raise up is, how accurate and reliable is the sensing technique? There may be two sensing errors: 1) the primary signal is not detected while the CR's signal can interfere with the primary user; 2) the primary signal is sensed but the CR's signal in fact would not interfere with the primary user. These errors are caused by different transmission powers adopted by the PTs and CRs as well as different fading paths that PT's and CR's signals go through.The sensing correctness can be enhanced by multiple cognitive radio users collaborating to sense. However, the communication cost for collaboration might be an issue. Another more severe issue is the existence of potential malicious users who reports false spectrum sensing information. The fundamental issue is that it is still doubtful whether the collaboration can improve the sensing correctness to the level that can be acceptable by primary network operators.

### *C. Issue of Malicious Radios*

As mentioned in previous subsection, if cooperative sensing is adopted, malicious secondary users may report false spectrum sensing information. Moreover, malicious users may also transmit in the sensing period (during which all CRs should keep quiet). It may happen that: 1) if there are PRs receiving, the malicious users will interfere with the PRs. In this case, there should be a monitoring system to detect such interference on PRs. Such monitoring system will bring extra cost. Also, such monitoring system requires monitoring sensors to be installed close to PRs, which inevitably needs the agreement from primary users. In this case, the principle of add-on mode, i.e. no modification to the incumbent system, is violated; 2) If all PRs are receiving, malicious transmission won't interfere with PRs but will mislead the benign CR users to believe there are active primary users nearby and thus give up the spectrum accessing opportunity. The malicious behavior in this case is usually referred to as licensed user emulation (LUE) or primary user emulation (PUE) attack [6]. Although there have been some methods to detect such LUE attack [7], but these methods cannot guarantee such attacks can always be detected. Moreover, these methods can only work to distinguish signal of single malicious CR from signal of single primary user, and can not work for the situation where multiple signals are mixed.

### *D. Issue of "Accessing after Sensing"*

Most CRNs adopt the pattern that CRs first sense spectrum in a period named as "quiet period" (a.k.a. sensing period) and next access the free spectrum in a period called as "working period" [8]. However, it may happen that the primary users are not active during the quiet period but turn active during the working period. In this case, CRs'transmissionwill interfere with active PRs. Another problem of the accessing after sensing pattern is that it requires the synchronization of all CRs to make sure all the CRs are all quiet during the quiet period. If the accessing after sensing pattern does not work, how about canceling the difference between the working period and quiet period, i.e. let the CR simultaneously sense and transmit, and if a CR sense the primary signal then the CR stop transmission? This is also infeasible because this requires the cognitive radio can clearly identify whether the sensed signal is from the primary user or the secondary user. As discussed in section 2.3, this requirement can be hardly achieved when multiple signals are mixed.

### *E. Issue of Market Motives*

The add-on installation method requires no cost for the existing primary systems, which is good from economics perspective. However, on the other hand, since the primary network is unaware of the activity of secondary network, the primary network can gain nothing from the secondary network, thus the existing telecommunication operators lack the motives to promote the CR technique.

## III. Potential of Integration Deployment Mode

Considering above formidable issues of the add-on deployment mode for setting up the secondary CRN systems, it is natural to consider the feasibility of a contrary deployment mode, primary-secondary network integration (named as P-S integration) mode, i.e. co-designing and co-operating the CRN and primary network. The integration mode also faces challenges from both the technique and economic side. In the following, we will discuss these challenges and potential solutions.

### *A. Technical Perspective*

The core challenge for the P-S integration mode is still to correctly detect the activities of PRs. Since now the primary networks can be modified, it is feasible to realize the reliable PR activity detection even in simplex primary networks. There are two potential methods for PR detection in simplex primary networks. The first method, referred to as aided PR detection, relies on the aid from sensors deployed close to PRs to detect the PR activity. The aiding sensors detect PRs' receiving channels by detecting the leaked power from their local oscillators [9]. The second method can be referred to as feed-backed PR detection. This method requires modifying the existing PR device so that the PR can feedback its reception status to the secondary users. From technical perspective, the first method is easier to realize since the sensors are externally deployed and hence requires no modifications onon incumbent communication devices. However, the first method cannot guarantee the reliable PR activity detection since theleaked power detection is not stable. The second method can provide accurate PR detection method but the modifications on PR device would be troublesome as well as costly. Another challenge for the P-S integration mode is thesystem architecture design. If the P-S hybrid network is centralized, i.e. a base station (BS) takes charge of the network,




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all the management load would concentrate on the BS. Such architecture design might not be very difficult since only the BS needs to be upgraded for network management. One method is: the BS can provide different QoS to primary users and secondary users; the BS should guarantee that the activity of secondary users will not lower the original QoS of the primary users. If the P-S hybrid network is a distributed network, the network management design is a challenging issue. A potential solution is: electing some nodes as monitoring nodes to monitor and regulate the behaviors of secondary users, so that CRs activities will be controlled not to interfere with primary users.

### *B. Economic Perspective*

From the economic perspective, the optimum new market should show opportunity for significant growth and have few entry barriers. The most formidable barrier for the P-S integration mode is the high cost for upgrading primary network devices. There are two possible strategies to work this problem out. One potential strategy is to catch a chance when a large-scale system upgrade happens. A typical large-scale system upgrade example is the transition from analog to digital TV. In such nationwide system upgrading, since the TV device change is necessary, it cost little to just add an extra function of communicating with the secondary user. The function can be added into the new-made digital TV directly or the set-top box. It's really regretful such good chance for deploying CRNs passed away since such transition was already finished in 2009 in US. To not miss some similar chances in the future, it is very necessary that more research be dedicated to the P-S integration mode to verify whether the P-S integration is feasible as early as possible. The second strategy is to compensate for the cost of changing the primary systems by allowing the primary users to charge certain fees from the secondary users. Therefore there should be a charging center installed in the network to make the charging rules and functions. For centralized P-S hybrid network, the charging center can be directly installed in the BS or it can be upgraded from the existing charging center in the BS considering most primary networks already have their own charging system. For distributed P-S hybrid network, each primary user should include a charging module to levy on secondary users. The fee a secondary user pays should be based on its spectrum usage.The spectrum usage information can be reported by secondary users and verified by some nodes assigned as monitoring nodes. This fee-charging strategy on the other hand can promote upgrading existing communication systems since there are incentives for both customers and system operators. For instance, it took many years to transit to digital TV system since t he TV operators and customers were reluctant to do so. If the P-S integration mode (i.e. TV network and CRN integration) were realized at that time, the incentives to make profit from CRNswould greatly promote and accelerate the transition process. Another immediate economic issue is where to start the initial market for the S-P integration. It may not be a wise idea to choose residential pools as its initial market. The reason being, the client base in such market is very fragmented and hence the existing device upgrading is costly as well as time-consuming. Maybe the initial market ought to target at national hotel chains. For instance the freed TV spectrum can be sold for customers to connect their computers to Internet without crowding in the unlicensed band. By starting the CR market at chained hotels, not only could the hotel chain provides sustainable revenue in the short term for the telecommunication operators, also such P-S integration system could gain national credibility.

## IV. Discussions and Conclusions

From the above analysis, maybe the integration deployment mode is more practical to build CRN in real life. However, there might be some other challenges for the integration deployment and some potential methods proposed in this paper used for integration deployment mode may turn out infeasible. The practical CRN deployment mode is still a debatable topic. In regard to uncertainness of the future CR development, there should be equal focuses on the two operation modes (add-on and integration) to realize practical P-S coexistence. However, it's regretful to see overwhelming majority effort has been placed in studying the add-on mode. So the main goal of this paper is to call for more attention and research on the P-S integration deployment mode for the practical CRN realization so that the CR technique can be implemented for daily business and personal life as early as possible.

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DOI: 01.IJRTET.8.2.47